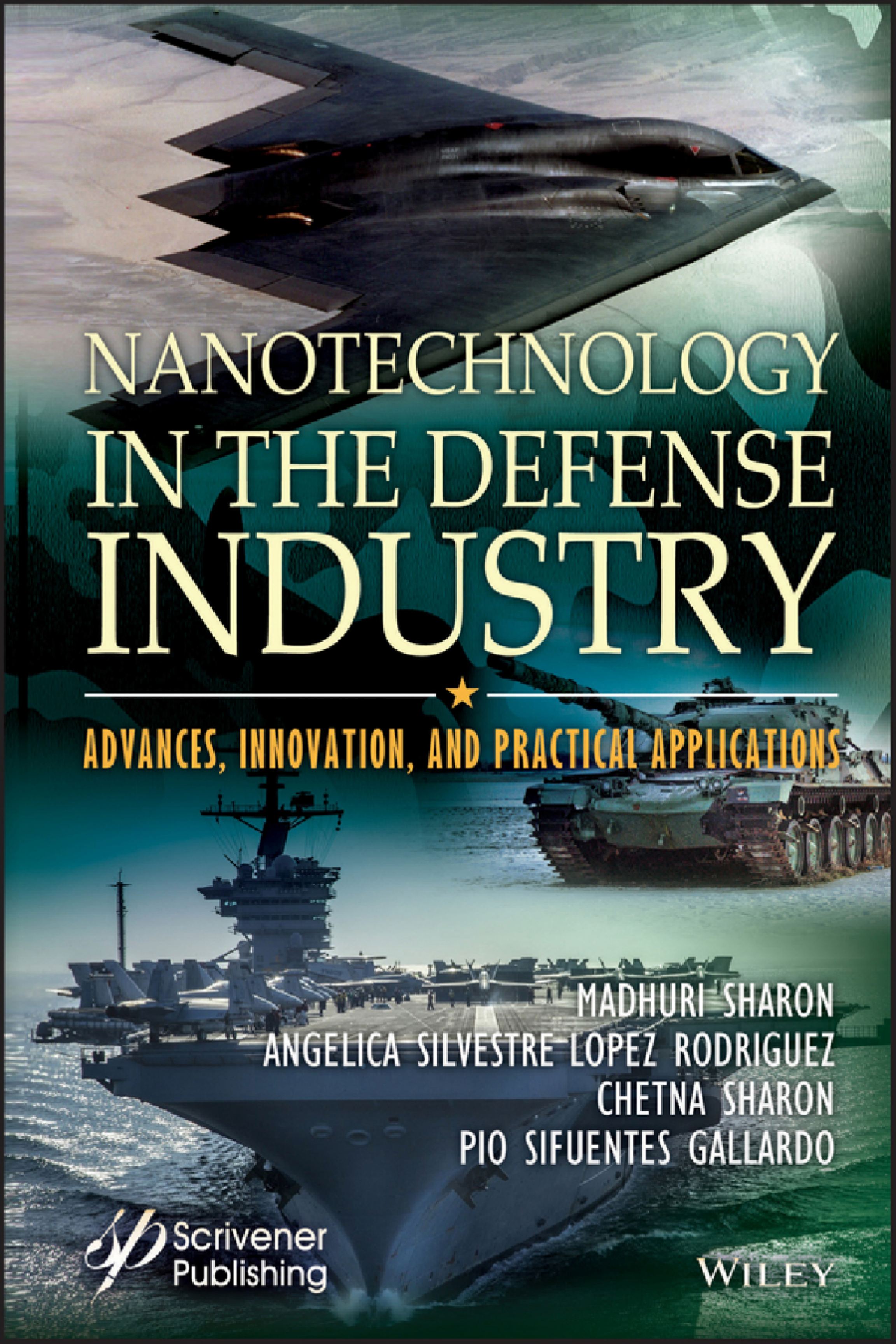

NANOTECHNOLOGY IN THE DEFENSE INDUSTRY

ADVANCES, INNOVATION, AND PRACTICAL APPLICATIONS

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Nanotechnology in the Defense Industry

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Advances in Nanotechnology & Applications

Series Editor: Madhuri Sharon

The unique properties of nanomaterials encourage the belief that they can be applied in a wide range of fields, from medical applications to electronics, environmental sciences, information and communication, heavy industries like aerospace, refineries, automobile, consumer and sports good, etc.

This book series will focus on the properties and related applications of nanomaterials so as to have a clear fundamental picture as to why nanoparticles are being tried instead of traditional methods. Since nanotechnology is encompassing various fields of science, each book will focus on one topic and will detail the basics to advanced science for the benefit of all levels of researchers.

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Advances, Innovation, and Practical Applications

by

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Preface

More than half the globe is confronted with war or war-like volatility and complex security situations. Scientists, including nanotechnologists, in every sphere are concerned and want to contribute. In this book, the challenges of our time, including new demands on the military at every level, are addressed. The need to provide defense personnel with practical tools necessary to succeed in this unpredictable and unstable world is of utmost importance, because the character of warfare is changing with time. This book articulates various areas of the defense support system that can be improved with the incorporation of nanotechnology, as well as ways to further develop a modern, future-oriented, attractive and competitive military support system.

With these concerns in mind, the chapters of this book are devoted to various areas of nanotechnological innovation afforded soldiers such as smart clothing and combat suits, medical therapeutic and diagnostic support, improved air and ground vehicles, portable energy sources, and nanosensors. Nanotechnology supported stealth and counter-stealth technologies, radar absorbing materials, the role of computers in aid of defense and textiles to help in camouflaging are also discussed. In addition, chapters have also been devoted to chemical and biological warfare.

Madhuri Sharon
Mumbai
August 2019

Foreword

The old adage, "With age comes wisdom and experience," holds true for the main author of this book, whom I have known for six years. My first encounter with her was in a spiritual meeting where I noticed her exceptional competency in executing holistic research, as she can inclusively think beyond the benefit of any particular organization or person attributed to her belief in spirituality. Dr. Madhuri Sharon epitomizes the life-long learner, always seeking novel approaches and skills. I have always loved and appreciated her dedication and significant contributions to the revolutionary field of nanotechnology, which is gaining considerable momentum in areas ranging from biomedical applications to their use in modern military systems.

The popular statement, "Small is the new big," is reflected in the enormous amount of applications of nanotechnology in the military domain. In this book, the authors present the advanced features of nanotechnology that can be well integrated into current military tactics used to fight wars. Nanotechnology provides multifunctional materials such as nanobattlesuits, nanoweapons, nanosensors, stealth and camouflage devices that facilitate effective protection and better battlespace awareness. Miniaturization of already existing military equipment to make it smaller, lighter weight and easily concealable can provide significant strategic advantages over the enemy.

This book fills the innovation gap that puts soldiers in peril and highlights the fact that an understanding of nanotechnology is necessary for technological advancements in the defense industry to occur in order to ensure the future security of countries.

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Nanotechnology's Entry into the Defense Arena

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Science is based solely on doubt-based, disinterested examination of the natural and physical world. It is entirely independent of personal belief. There is a very important, fundamental concomitant - that is to accept absolutely nothing whatsoever, for which there is no evidence, as having any fundamental validity.
Nobel Laureate Sir Harold W. Kroto

1.1 Introduction

When nanotechnology emerged as a new science, it had attracted the attention of scientists from all branches of science the world over. Similarly, people from different domains of life and governance started realizing the impact of nanotechnology. Authorities from the military, security and defense arena also started thinking about the use of this technology. It was realized that nanotechnology would make a big difference in areas such as troop functionality, high-speed conveyance and

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capacity, safety of soldiers, betterment of aircraft, systems for command, control, communication and surveillance, automation and robotics, innovative sensors, advanced war fighter and battle systems capability, electrochemical power, such as batteries or fuel cells, and many more. Nanotechnology is seen as being a technology of national importance to the economy and security by many developed countries especially in the defense sectors. This chapter is about the area of defense that is being impacted by nanotechnology. Almost all countries across the globe are experimenting to understand how this Small Science will help protect their country.

1.2 What Is Nanotechnology

Let us very briefly look at this topic. One may write volumes on what nanotechnology is. But that would be beyond the scope of this book, because this book is about the specific application of nanotechnology in defense. However, in a nut shell, the emergence of nanotechnology, which is a science that deals with the properties of materials with dimensions of 1–100 nm (Figure 1.1), is a result of the fruitful thinking of the visionary

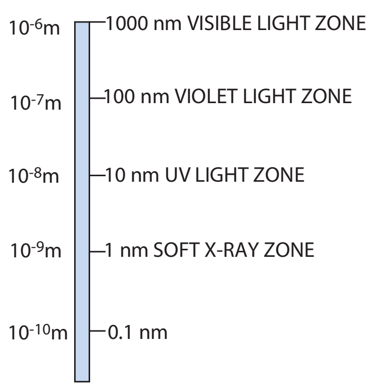

Figure 1.1 Nanometer scale.

Nobel laureate Professor Richard Feynman. Nanotechnology has revolutionized almost every field such as medicine, electronics, information technology, geology, space technology, material science, etc. Enough evidence on this subject has been provided to be able to state that *at macroscale and microscale objects behave differently than that at nanoscale*. The behavioral as well as the structural properties of a nano-object change. When one starts reducing the size of a solid from micro-level to nano-level, its appearance completely changes, especially where metals are concerned. Gold appears lustrous yellow at macroscale, but when brought to nano-level its color turns to red or blue depending on the size.

Such alterations in properties of nanomaterials have created vast applications in Physics, Chemistry, Materials Science, Computers, Engineering, Medical and Biosciences, etc. No wonder venturing into the tiny domain of atoms and molecules is catching on. The main aim and objectives of Nanotechnology and Nanoscience is to unravel as well as comprehend the appearance of strange but useful traits in nanoparticles when they venture into the realm of nanoscale (1–100 nm). The emergence of the physicochemical and optoelectronic properties of nanoparticles is primarily due to confinement of electrons within particles of dimensions smaller than the bulk electron delocalization length. This ability to tune the optical absorption or emission properties (quantum dots) by simple variation in nanoparticle size is particularly attractive in the facile bandgap engineering of material and the growth of quantum dots.

In a nutshell, nanotechnology is the branch of technology that deals with dimensions and tolerances of less than 100 nanometers, especially the manipulation of individual atoms and molecules, or is the manipulation of matter on an atomic, molecular, and supramolecular scale. Such small engineered materials exhibit unique properties that are not found in their bulk counterparts.

The unique properties of nanomaterials that are being utilized for various applications are their chemical reactivity, mechanical strength, electrical properties, optical properties, thermal properties, and durability and quantum effects.

It is difficult to say which country's defense department was first to start working out the possibility of using nanotechnology. However, strong participation of the United States Department of Defense in areas such as sensitive spectrum analyzer 3Hz – 50 GHz, quantum dots for nanoelectronics and sensors, highest Q mechanical resonator (cantilever, nanowire) for chemical sensing, nanomagnetic materials for DNA detection, nanoscale aluminium particles for energetic materials, smallest individual organic light emitting diodes (OLED) device, long shelf life packaging for food (nanoclay PE composite), high strength fibers from twisted nanotube yarns and maskless lithographic process for semiconductors are evidence that they have been investing in working out the applications of nanotechnology.

Out of the Asian countries, Japan is the leading up-and-coming nation investing in nanotechnology, followed by China and Taiwan.

In European countries, Germany, Russia, the United Kingdom, the Netherlands, etc., are running programs in nanotechnology.

1.3 Nanotechnology Offers Innovative Opportunities for Defense

Initially, many thought that nanotechnology applications offered more hype than hope. But as many fantasies started becoming realities, the considerations and joint as well as separate efforts of scientists have reached a consensus that nanotechnology can provide strength and enhanced efficacy to many requirements of the defense arena. The area in which nanotechnology inputs are being envisaged as a must are its applications for (i) soldiers, (ii) security, (iii) weapons, (iv) aeronautics, (v) naval vessels, (vi) vehicles, (vii) satellites and (viii) logistics.

1.4 Nanotechnology for Soldiers

At the moment the maximum focus for the safety of soldiers is on developing a nano combat suit, which should be as thin as spandex and contain health monitors and communications equipment, acts as a shield from bullets, and can protect from biological and chemical attacks. This is for the well-being and security of soldiers. Nanotechnology is crucial for such development because without miniaturization such functionalities cannot be adapted to lightweight, wearable systems.

1.4.1 Smart Clothing Using Nanotechnology for Various Applications

Using the process of manipulating materials on an atomic or molecular scale, clothes are manufactured that have the following characteristics:

- Because it has *greater tolerance to temperature* change, nanotechnology-based fabric can warm or cool the body.
- It is possible to *charge a phone* using a fabric that is solar-powered and to recharge a cell phone or iPod. The change in temperature can open or tighten the weaving pattern of the fabric because the fibers of the fabrics can be modified so their physical properties change with temperature.
- *Anti-microbial nanofabrics* coated with antimicrobial nanoparticles can be used to protect soldier's bodies from microbial infection.

- Another possibility that is being envisaged is to use fabrics coated with *encapsulated insecticides to eliminate mosquitoes.*
- In case a soldier faces smog or toxic gas, scientists are working on fabrics loaded with encapsulated gases that can be released to combat the condition.
- *High-strength fiber* made up of a composite of carbon nanotube impregnated in polymer can be used in nonwoven mats.
- *Multi-Functional Textiles* is another fantasy for the protection of soldiers that is being considered by modifying and functionalizing the surface properties by mixing yarn with nanomaterial and then weaving fabric from it. The new properties that can be exploited will be for the purposes of *sensing,* energy harvesting and energy storage.

1.4.2 Invisibility and Adaptive Camouflage

One of the ongoing dreams of scientists that has been dramatized and presented in many works of fiction and movies is a disappearing or invisible man. For this, one approach that is being considered is to make a cloak or fabric by *manipulating light* so that the soldiers wearing it cannot be seen or disappear. An "ultrathin invisibility skin cloak for visible light" is an outcome of this idea [1]. It is also known as *metamaterial cloaking* as it uses metamaterials, along with manipulating the paths traversed by light through a novel optical material. Metamaterials direct and control the propagation and transmission of specified parts of the light spectrum and render the object invisible.

This result is based on the fact that how we see any object depends on the role of light that bounces off the object and becomes distorted. This distortion is due to the angles and curves of the object. However, if the object is smaller than the wavelength of visible light (300–700 nm), it passes straight through and cannot be seen. That is why even after adding a very high magnification a nanoparticle cannot be seen under the light microscope. The development of a cloak that makes the object invisible is based on this principle. To make a cloak material look invisible it should be fully covered with tiny gold blocks of different nanosizes. Though it seems beyond reach today, soon it will become a reality; especially with the recent report of a dielectric "surface wave cloak" from Hao's group [2], this fantasy seems to be a possibility in the near future. They have made a cloak from engineered gradient index materials (seven ultrathin layers that each had different electric properties) using nanocomposites to control surface wave propagation through advanced additive manufacturing and coated a curved metal plate surface, about the size of a tennis ball, with their cloak. The seven ultrathin layers can hide whatever object they cloak from interacting with electromagnetic waves. Otherwise, the electromagnetic waves would bump into the object and scatter in different directions.

This device is designed analytically and validated through numerical simulations and measurements, showing good agreement and performance as an effective surface wave cloak. The unique aspect of this "surface wave cloak" is that it can make curved surfaces appear flat when they come in contact with electromagnetic waves. The cloak was made out of a gradient-index material with seven ultrathin layers that each had different electric properties. This technology can also be applied to escape detection by radiated probing.

Adaptive camouflage is another approach which is focusing on *electrochromic camouflage,* i.e., using nanoparticle coated fabric which changes colors instantly to blend in with the surroundings. The change in color of the fabric is based on reflective electrochromic device. Adaptive camouflage changes color in response to the environment. This chameleon sheet can be used for draping tanks, vehicles or even as soldier's suit.

In their patented work, Gorodetsky and Xu explain that this device consists of primary color tone plaque that is the main color of the entire fabric and secondary color tone plaque which is patched on this fabric. The fabric is a flexible conductive textile with ion storage layer, an electrolyte layer, the main color camouflage patched of conductive fabric, electrochromic polymer layer and a transparent protective film layer and a conductive flexible conductive fabric camouflage fabric respectively. It is connected to a positive and negative power supply through a wire. Since it uses two fabric electrodes, it makes fabric wearable. Moreover, the electrochromic polymer and a reflective structure having low voltage can be artificially controlled between two or more camouflage patterns that change color fast.

Luminex using integrated glass fibers + LED source is making luminescent fibers by weaving fiber optics into fabric. Super bright LEDs are attached to these colorless fibers that are controlled by a microchip (powered with a battery), which instructs them to emit different colors. An optical sensor is added; hence, the clothes glow by constantly changing colors to match the surroundings.

1.4.3 Armor Fabric

Especially for defense personnel, soldier's antiballistic and shatterproof armor will be of great benefit. It will not only benefit the military, but also fire fighters, police officers, and other emergency responders. Present-day armor, i.e., *Smart Armour,* is not only for protection but is also being researched using nanotechnology so that it can sense the impact of a bullet or shrapnel and automatically stiffen, which should make it even more resistant to penetration and less cumbersome than the ceramic-plate armor troops now wear. Researchers are working on the following materials for use as armor.

1.4.3.1 Artificial Muscles

A concept of weaving artificial muscles into armor that could enable soldiers to leap tall walls is being considered. This material uses nanotechnology and electricity and flexes when jolted by electricity and then relaxes when the electricity is turned off.

1.4.3.2 Strong, Lightweight and Self-Repairing Material

Nature has always been the guiding force for scientist for many discoveries. The use of abalone sea snails is one such guiding idea for scientists in their search for strong and lightweight armor. The shells of abalone are strong, lightweight and can self-repair. For this purpose, improved body armor using SiO or TiO_2 nanoparticles embedded in epoxy matrix is being explored. SiO nanoparticles in a liquid polymer harden on ballistic impact (*shear thickening fluid*). Similarly, iron nanoparticles dispersed in inert oil harden on stimulation with an electrical pulse (*magnetorheological fluid*).

1.4.3.3 Tungsten as Ultrastrong Material

An attempt is currently being made to use tungsten as a basic material since it is five times stronger than steel and twice as strong as currently used impact-resistant material. It is to be used as a new nanomaterial for body armor so as to give ballistic protection. It will be useful for vehicle armor, shields, helmets, and protective enclosures.

1.4.3.4 Carbon Nanomaterials

Carbon nanomaterials (CNMs), especially those having onion-like layering or are multiwalled, i.e., multiwall carbon nanotubes (MWCNTs) (Figure 1.2), have also shown strong and durable properties when embedded in polymers. Investigations are underway to make nanosized umbrellas that open to seal the cloth's

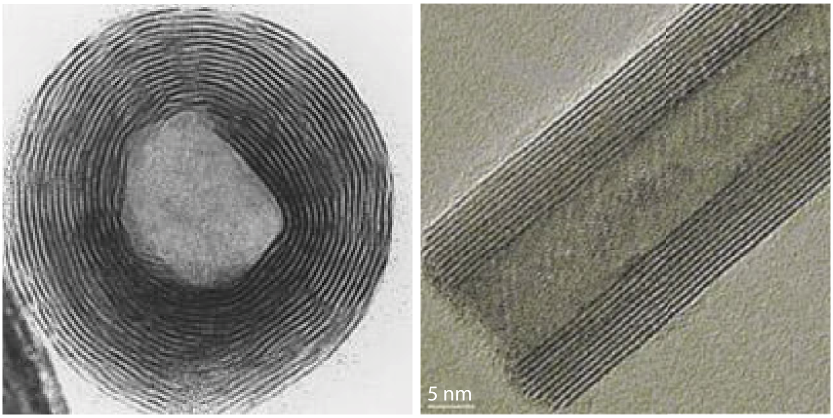

Figure 1.2 TEM images of a multiwall carbon nanotube from two different angles showing lumen in the center surrounded by many walls.

pores, making it impervious to airborne chemicals and pathogens. That would be much easier and lighter than the current equipment required for protecting against biochemical warfare.

1.4.3.5 Future Combat Suits

Future combat suits incorporating the above-mentioned developments in nanotechnology- and nanoelectronics-based textiles will protect against various threats (bullets, grenade fragments, bioagents, chemical agents), will be light, and will monitor vital signs with printed and embedded physiological sensors on textiles (i.e., ECG (electrocardiography) sensors to monitor heart rate, respiration, temperature, dehydration). These suits will have a power grid and energy generating system using ZnO nanowires on textile fibers which will act as piezoelectric nanogenerators. To face extreme temperature conditions, thermal management technologies for textiles use carbon nanofibers and CNTs for heat conductance, ventilation, insulation and local cooling. They will have external sensors for communication and identification. Adaptive camouflage has already been discussed above.